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The Elusive Diploic Veins: Anthropological and Anatomical Perspective

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ABSTRACT Diploic veins (Canales diploicae), which were identified in dogs by Dupuytren more than 200 years ago (Hecker [1845] Die anatomische Verhaltnisse und Krankheiten der Venae diploicae und Vasa emissaria. Erfahrungen und Abhandlungen im Gebiete der Chirurgie und Augenheilkunde. Erlangen), have remained inadequately understood and scantily referenced in the anatomical and anthropological literature. The tunnels formed by diploic veins are among the few known skeletal markers of soft tissue alteration. Protected by two bony laminae, diploic vein tunnels often resist postdepositional destruction and may provide a new way to assess living and extinct hominid populations. This basic research was carried out to enable future utilization of the diploic venous channels in anthropologic research. In the present study, diploic venous channels were observed radiographically in 108 human adults aged 19 years and above, 18 infants and children aged 1–18 years (Hamann-Todd Osteological Collection), eight fetuses aged 7–9 months (the Johns Hopkins Collection), and seven nonhuman primates (Hamann-Todd Osteological Collection). In addition, seven documented cases of parents and children were radiographed for genetic evaluation (Osteological Collection of The Hungarian Natural History Museum). Five distinct diploic distribution patterns were identified and described in this study. This was at variance with the impressions reported in dissection-based studies. Independence of diploic vein pattern from demographic (gender and age) and size factors and their tendency to be symmetrical make them amenable and reliable traits for skeletal population study. Diploic vein patterns appeared to be more complicated in humans than in

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nonhuman primates, raising the possibility of future phylogenetic applications. Am J Phys Anthropol 108:345–358, 1999.

Discrete skeletal markers, whether genetic, enthesopathic, or developmental in nature, are widely used to estimate the biological relationships between individuals and populations (e.g., Corruccini, 1974; Finnegan and Cooprider, 1978; Rosenberg et al., 1983). Most osseous markers are of limited, local, biological (functional) significance. Because the archaeological record is generally restricted to the analysis of skeletal remains, we have little information on soft tissue. Some normal soft tissue phenomena, however, leave decipherable impressions on bone (e.g., the middle meningeal artery on the inner aspect of parietal bone). Diploic vein calvarial imprints provide a unique opportunity to indirectly visualize a portion of the vascular tree, an organ system not generally amenable to study on hard tissue. An understanding of these imprint patterns may provide important clues regarding a population's origin and migration, social customs (inbreeding), and even climactic conditions.

The calvarial diploe contains a number of large veins. These veins anastomose with each other and with a network of microscopic venous channels. All diploic veins are lined by a single endothelial layer and are devoid of valves. They communicate with the dural sinuses and pachymeningeal veins on the one hand and with pericranial veins on the other via emissary veins. As the diploic veins are positioned between two cranial plates, diploic vein imprints are usually protected from the postmortem processes, an advantage over some other skeletal markers. This sheltered location has made dissection-based study extremely difficult. Radiographic examination provides a simple, accurate method for the study of these vascular channels (Lindblom, 1936).

Diploic vein morphology has received little attention in the anatomical and anthropological literature and is typically limited to hypothetical representations of their distribution (Fig. 1A,B). Most textbooks (e.g., *Gray's Anatomy* [Warwick and Williams, 1973]) suggest that diploic veins develop into four major channels at about 2 years of age. The functional significance of the diploic venous system remains unclear. Cabanac (1993), Baker (1979), Zenker and Kubik (1996), and many others have maintained that the diploic veins are associated with brain cooling. Venous blood from the scalp, cooled by a wealth of sweat glands, passes to the pachymeningeal veins by way of the diploic venous system.

The aims of the present study were 1) to clarify the nature of diploic venous patterns by radiologically documenting their anatomical characteristics and distribution and 2) to examine their potential utility in anthropological research by developing a classification system applicable to population analyses, by assessing their relationships to demographic parameters such as sex, ethnic origin, and age, by assessing their relationships to body size parameters (i.e., skull size, brain volume), by assessing the ontogeny (onset of the process) of diploic vein formation, and by assessing their phylogeny via comparative analyses with nonhuman primates.

MATERIALS AND METHODS

One hundred and eight human skulls of individuals over 19 years of age were randomly selected from the Hamann-Todd Osteological Collection (HTOC) housed at the Cleveland Museum of Natural History (CMNH). These were analyzed as 10 year cohorts. In addition, the skulls of 18 children (aged 1–18 years) and seven nonhuman primates from the HTOC were studied. Eight fetal skulls (7–9 months of age) from the Johns Hopkins Fetal Collection (presently housed at the CMNH) were also randomly selected and analyzed in the present study. To explore the genetic component of diploic vein patterns, we studied skull radiographs of seven families. These skeletons, currently housed in the Hungarian Natural History Museum, Department of Anthropology, were originally found within a church basement in coffins. Included among the church archives was detailed information on the de-

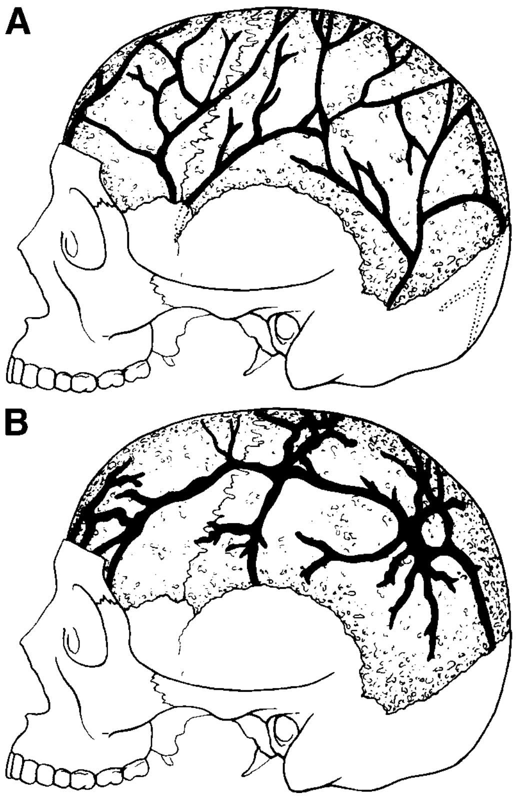

Fig. 1. Schematic illustration of literature representations of diploic vein distribution: **A.** re drawn from Gray's Anatomy (Warwick and Williams, 1973). **B.** re drawn from Cunningham's Text-Book of Anatomy (Brash and Jamieson, 1937).

ceased, including name, familial relationships, sex, and age.

The demographic characteristics of the adult portion of the sample (age, sex, ethnic origin) are delineated in Table 1. The cranial module (cranial length + breadth + height/3) was utilized to estimate skull size (Bass, 1987).

All adult skulls, with the exception of the Hungarian sample, had previously been sagittally sectioned, facilitating lateral x-rays without the superimposition of shadows. Lateral x-rays of each hemicranium were separately obtained using a Hewlett Packard (Corvallis, OR) Faxitron Cabinet X-ray system. Selected oblique and superior-inferior x-ray views were also obtained to clarify diploic vein drainage patterns. To examine the resolution of the x-ray method, we also injected several skulls with iodine mixed

TABLE 1. Demographic characteristics of the adult sample

Age in years	African-American Male	African-American Female	European-American Male	European-American Female	Total
20–29	9	3	1	4	17
30–39	3	6	3	3	15
40–49	5	9	3	3	20
50–59	3	3	5	2	13
60–69	3	3	6	4	16
70–79	5	0	2	5	12
80+	4	3	5	3	15
Total	32	27	25	24	108

with water (ISOVUE-300; iopamidol injection 61%). Adult skull x-rays were taken at 150 milliamp.sec and 55 KVp, subadult skulls at 125 milliamp.sec and 40 KVp, and infant and fetal skulls at 100 mA/sec and 30 KVp. The nonhuman primate skulls (*Gorilla gorilla, Pan troglodytes,* and *Pongo pygmaeus*) were x-rayed at 135 mA/sec and 45 KVp.

Intensity scale

Preliminary review led to the establishment of a four grade intensity scale derived on the basis of the length, width, and area occupied by the diploic veins.

Intensity grade I. The diploic veins are barely perceived. Occasionally a single short (2–4 cm), narrow (>1 mm in diameter) vein is present.

Intensity grade II. A dominant single diploic vein, 4–10 cm in length and 1–2 mm in width, with few short tributaries is found.

Intensity grade III. A large diploic vein, 10–15 cm in length and 2–4 mm in width, with several minor and one or two major tributaries is observed. Some tributaries extend for several centimeters.

Intensity grade IV. Several wide, interconnecting major tributaries 15 or more centimeters in length and over 4 mm in width or one major channel associated with venous lakes is noted. Dilated areas can reach 8 mm in width.

Demographics and statistics

The relationship of diploic vein pattern and intensity to demographic parameters

TABLE 2. Frequency distribution of diploic vein pattern by intensity

Type[2]	Intensity grade[1] I	II	III	IV	Total
Spider (Fig. 2a,b)	0	6	2	1	9
Thousand lakes (Fig. 3c,d)	0	2	0	2	4
Serpentine (Fig. 2c,d)	5	7	2	0	14
Coronal (Fig. 2e,f)	0	6	3	0	9
Vine (Fig. 3a,b)	34	21	4	0	59
Hybrid (Fig. 3e,f)	0	0	5	1	6
Indeterminate	7	0	0	0	7
Total	46	42	16	4	108

[1] The four grade intensity scale was derived on the basis of the length, width, and area occupied by the diploic veins (see text).
[2] The different types are identified under Materials and Methods (see text).

TABLE 3. Frequency distribution of diploic vein pattern by sex and ethnic origin[1]

	Male (n = 57)		Female (n = 51)	
Type[2]	A-A	E-A	A-A	E-A
Spider (Fig. 2a,b)	4	1	2	2
Thousand lakes (Fig. 3c,d)	2	1	0	1
Serpentine (Fig. 2c,d)	9	1	3	1
Coronal (Fig. 2e,f)	0	3	1	5
Vine (Fig. 3a,b)	14	16	17	12
Hybrid (Fig. 3e,f)	3	2	1	0
Indeterminate	0	1	3	3
Total	32	25	27	24

[1] A-A, African-American; E-A, European-American.
[2] The different types are identified under Materials and Methods (see text).

(Tables 2–6) was established using the chi-square test. To assess the relationship between diploic vein pattern and intensity and skull size (measured in accordance with Bass, 1987) and brain volume (as measured by Todd and his coworkers during autopsy), 20 male skulls were divided into two groups (Table 7) (ten with grade I intensity and ten with grades 3 and 4) and a *t*-test performed. The Kolmogorov-Smirnov two-sample test was used to test the distribution of diploic vein patterns for gender and race.

RESULTS

The following is a description of diploic venous patterns according to cranial region.

Diploic veins of the parietal bone

The parietal bone, with the greatest number of diploic channels, showed striking variation in their distribution and drainage. In the present study, five distinct patterns and seven categories of venous distribution were outlined based on overall anatomic presentation.

Spider type (Fig. 2A,B). This category is characterized by a central lacuna (the body) surrounded by four or more major channels (legs) varying in length from 20–70 mm. The widest channels (3–6 mm) lie adjacent to the central lacuna and narrow distally. The central lacuna (dimensions, approximately 15 $\times$ 15 mm) is usually located at the upper mid-portion of the bone. The superior arm(s) is contiguous with the parietal foramen. The inferior arm(s) connects the mastoid foramen and the transverse or sigmoid sinus. The anterior arms connect to the sphenoparietal sinuses. The posterior arm, if present, is contiguous with the occipital diploic vein. The spider pattern was found in 8.3% of the skulls.

Serpentine type (Fig. 2C,D). This formation has a single long (>100 mm), 4–6 mm wide, river-like channel with isolated short tributaries. The vein makes several curves as it traverses the parietal bone, mainly in the anteroposterior direction. It is contiguous with the sphenoparietal sinus and the occipital diploic vein (Fig. 4). Small channels connecting the straight sinus and parietal foramen are occasionally identified. The serpentine type was found to be present in 12.9% of the skulls.

Coronal type (Fig. 2E,F). This configuration possesses one wide (3.5–5 mm), long, straight channel within the parietal bone, which runs parallel to the coronal suture and the anterior (ascending) branch of the middle meningeal artery. Lacunae and narrowing are notably absent in this pattern, and associated channels are rarely observed. It is contiguous with the sphenoparietal sinus and middle meningeal vein. The coronal type was found in 8.3% of the skulls.

Vine or bonsai type (Fig. 3A,B). In this category, one major vertical stem extends superiorly for several centimeters on the posterior aspect of the parietal bone. It subsequently narrows and branches or bends forward, continuing towards (and sometimes into) the frontal bone. It is contiguous with the transverse-sigmoid sinuses. This

TABLE 4. Diploic pattern[1] frequency distribution by age

Age in years	Spider	Thousand Lakes	Serpentine	Coronal	Vine	Hybrid	Indeterminate	Total
20–29	3	0	4	0	6	2	2	17
30–39	2	0	3	1	7	0	1	14
40–49	3	1	3	0	11	1	1	20
50–59	0	0	1	1	9	2	0	13
60–69	0	1	2	5	8	0	1	17
70–79	1	2	0	1	8	0	0	12
80+	0	0	1	1	10	1	2	15
Total	9	4	14	9	59	6	7	108

[1] The different types are identified under Materials and Methods (see text).

TABLE 5. Frequency of intensity distribution grades by sex and ethnic origin[1]

Intensity grade[2]	Male		Female	
	A-A	E-A	A-A	E-A
I	12	10	13	11
II	12	8	11	11
III	6	5	3	2
IV	2	2	0	0
Total	32	25	27	24

[1] A-A, African-American; E-A, European-American.
[2] The four grade intensity scale was derived on the basis of the length, width, and area occupied by the diploic veins (see text).

TABLE 6. Intensity[1] distribution frequency by age

Age	I	II	III	IV	Total
20–29	9	4	3	1	17
30–39	7	6	2	0	15
40–49	7	8	5	0	20
50–59	5	5	2	1	13
60–69	7	7	1	1	16
70–79	6	5	0	1	12
80+	5	7	3	0	15
Total	46	42	16	4	108

[1] The four grade intensity scale was derived on the basis of the length, width, and area occupied by the diploic veins (see text).

was the most prevalent pattern, appearing in 54.6% of the cases examined (59 of the 108 cases) (Table 2).

Thousand lakes type (Fig. 3C,D). This category is characterized by complexes of lacunae, concentrated mainly in the midparietal region. The lacunae occupy a large area (30 × 70 mm) of the diploic space. They have ill-defined channels, which communicate with the main emissary veins. No dominant channel is present. The thousand lakes type was identified in 3.7% of the skulls.

Hybrid pattern (Fig. 3E,F). One of two additional patterns delineated, the hybrid pattern is a combination of two or more of the five pattern types named above. The hybrid pattern was observed in 5.6% of the skulls.

Indeterminate pattern. The second additional pattern dilineated is the indeterminate pattern. In this pattern, due to an inadequate degree of vascularity, no particularly salient feature is noted. This condition was present in 6.5% of the skulls.

Diploic veins of the frontal bone

The diploic vein pattern in the frontal bone (visible in 77% of lateral radiographs) is usually composed of one or two major channels (on each side) with minor branches, running vertically within the midfrontal region (Figs. 2B,F, 3F, 8). Detectability of frontal diploic vein patterns correlates with the clarity of the parietal diploic vein pattern (Fig. 3D). It is contiguous with the superior ophthalmic vein, middle meningeal vein, and sphenotemporal sinus. Minor channels may connect with the superior orbital vein. Connecting channels between frontal and parietal veins are occasionally present (Figs. 2D, 3B, 9).

Diploic veins of the occipital bone

Occipital diploic veins are a minor component of venous drainage and do not show any clear pattern. A parasagittal occipital diploic vein or tiny branches associated with the major sinuses, mastoid foramen, or even the foramen magnum may be noted. The area above the supranuchal line is usually more vascularized than the area below it. Extension of the serpentine-type parietal diploic pattern across the lambdoid suture into the inion region is common (Fig. 4).

TABLE 7. Metric characteristics of skulls with underdeveloped (group A) and well-developed (group B) diploic veins

	Cranial length (mm)	Cranial breadth (mm)	Cranial height (mm)	Midfrontal thickness (mm)	Midparietal thickness (mm)	Cranial module (index)	Brain volume (cm^3)
Group A							
Minimum	172	135	109	3.8	4.5	140.7	1,263.8
Maximum	187	150	126	10.8	10.5	153.0	1,587.9
Average	180.2	142.6	117.7	6.3	7.4	146.8	1,423.1
STD	4.1	5.6	5.6	1.9	1.6	3.9	96.0
Group B							
Minimum	167	135	115	3.4	4.9	143.7	1,374.4
Maximum	203	153	133	9.8	11.3	159.7	1,639.4
Average	186.0	143.6	122.4	5.9	8.0	150.7	1,481.7
STD	11.1	5.7	5.4	1.6	1.7	5.0	103.6
P value[1]	0.1606	0.7131	0.0865	0.6452	0.4435	0.0854	0.2914

[1] *T*-test.

Symmetry

This split skull study demonstrated a tendency towards symmetry of pattern and intensity (but not in the details) between the two hemicrania. The two sides, while similar, cannot be superimposed as mirror images (Figs. 5, 9). No two of the 108 cases were identical in appearance, and side dominance was not recognized.

Diploic vein intensity

The distribution of diploic vein pattern by intensity is outlined in Table 2. Only a very small percentage (3.7%) of skulls manifested an extremely developed diploic venous system (intensity grade IV), yet the differences among the types were pronounced. All six hybrid cases fell into grades III and IV, but most cases of the vine type (55 of the 59) fell in grades I and II. By definition, all seven indeterminate cases fall within grade I.

Diploic veins, skull size, and brain volume

There is no statistically significant trend towards larger skull size or increased brain volume among individuals with higher grade diploic vein intensity (Table 7). However, skull measures (except for cranial thickness) were greater in group B, the group with the more intense diploic patterns. Evaluation of a larger sample is required to assess if this trend is indeed significant.

Diploic vein inheritance

No conclusions can be drawn regarding the mode of diploic vein inheritance due to the small size of the familial sample. Nevertheless, two comments can be made: 1) in two families observed in this study, striking similarities in diploic vein pattern between one of the parents and the parent's offspring were noted and 2) the individuality of diploic vein pattern is preserved within families.

Demographic aspects of diploic veins

The distribution of diploic patterns and intensity by race, sex, and age is presented in Tables 3–6. Diploic pattern distribution does not seem to be affected by any of the demographic parameters studied. The Kolmogorov-Smirnov two-sample test was not significant ($P = .05$) when any two distributions were compared. Sex seems to be related to the intensity of diploic impression. Fifteen of the 57 male skulls (26.3%) manifested intensity grade III or IV, compared with only five of the 51 female skulls (9.8%) ($\chi^2 = 4.863$, $P = .0274$, df = 1). No female skulls manifested grade IV intensity.

Forensic aspect

Diploic vein patterns appear to be analogous to fingerprints in so far as they follow one of several general patterns but remain unique to every individual. No two individuals in the present sample possessed absolutely identical patterns. For obvious reasons, however, this method is not practical for everyday forensic purposes as fingerprints are. Nevertheless, taking records of diploic vein pattern from individuals involved in high risk activity is recommended.

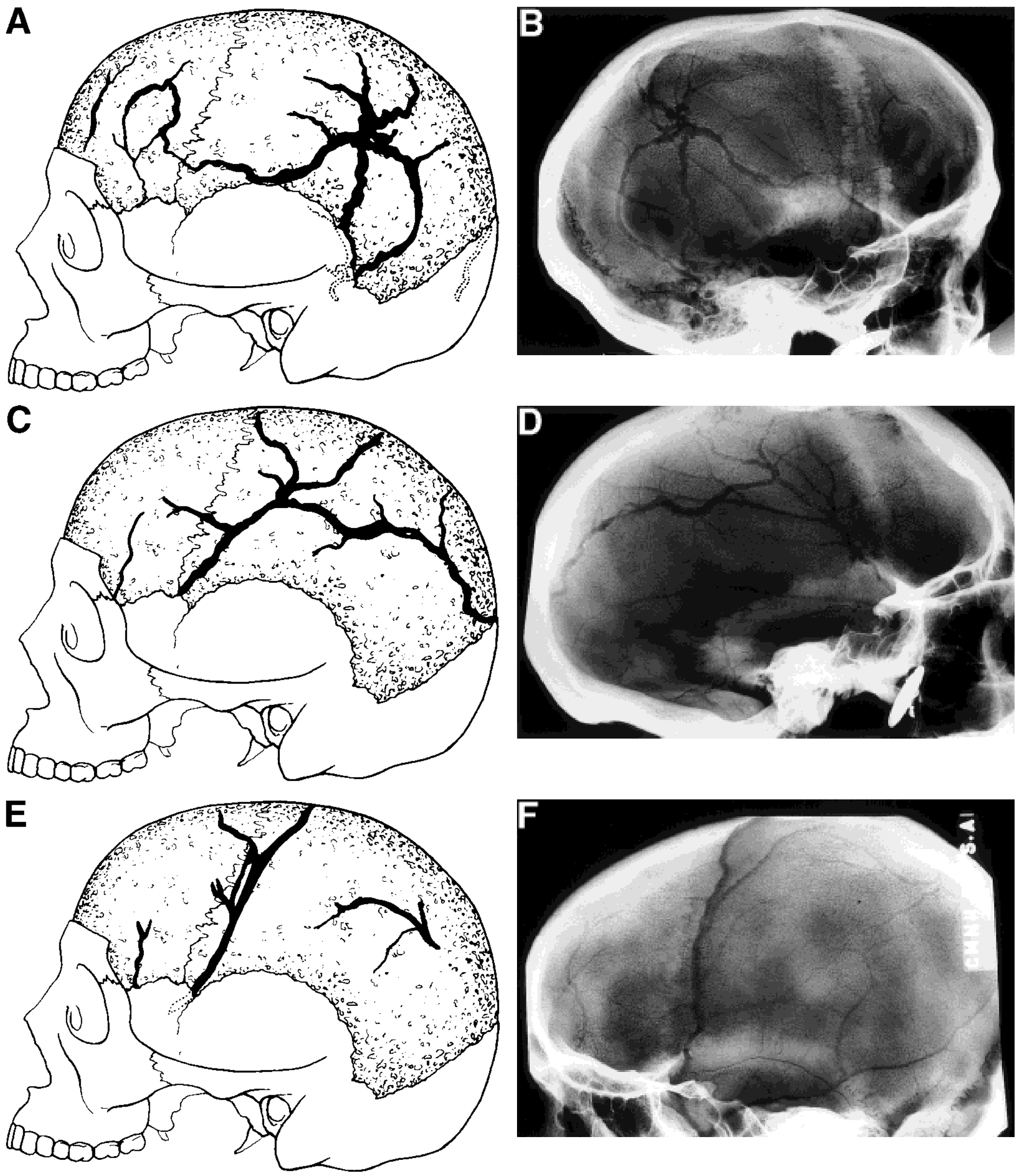

Fig. 2. Lateral x-ray views and schematics of diploic vein patterns. **A,B:** Spider type. Central lacuna with four or more major channels. **C,D:** Serpentine type. Single long, wide channel with isolated short tributaries. **E,F:** Coronal type. Single wide, long, straight channel running parallel to the coronal suture.

Ontogeny

The diploic venous system is recognizable radiologically at term, as documented by its presence in 7–9 month fetuses (Fig. 6A). The diploic pattern appears fully established by age 5 (Fig. 6B). Vascular channel diameters may continue to increase through late childhood.

Phylogeny

Although to a much lesser extent and intensity than in humans, diploic veins were

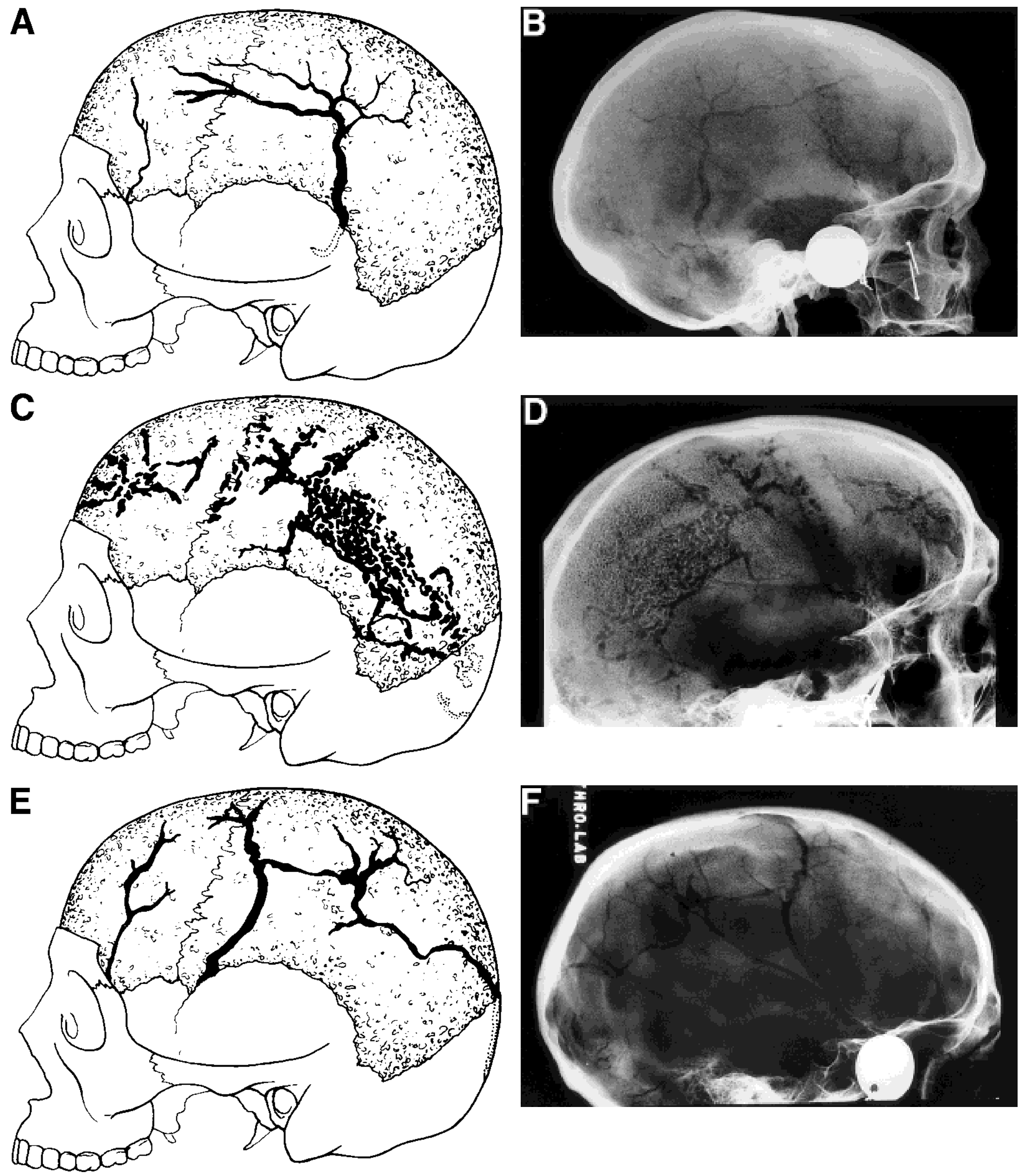

Fig. 3. Lateral x-ray views and schematics of diploic vein patterns. **A,B:** Vine or bonsai type. One major vertical stem extending superiorly for several centimeters, subsequently becoming narrow and vague and branching forward, continuing towards the frontal bone. **C,D:** Thousand lakes type. Complexes of lacunae, concentrated mainly in midparietal region. **E,F:** Hybrid type. Combination of serpentine and coronal diploic vein patterns.

radiologically detected in gorillas, chimpanzees, and orangutans (Fig. 7). In the present sample, the level of intensity did not exceed grade I. None of the patterns that were routinely observed in humans were detected. Instead, one or two isolated vertically oriented channels were noted.

Fig. 4. Oblique x-ray view of diploic vein pattern. Continuation of the serpentine vein with occipital diploic vein (notice lambdoid suture to the left).

DISCUSSION

Validity of the classic anatomical textbooks' description

Diploic veins were discovered relatively late in anatomical history by Dupuytren (Hecker, 1845) and described by Breschet in 1829. Breschet (1829) outlined four major drainage channels (one frontal, two temporal, and one occipital) within the diploe. This approach, which was firmly adhered to in the German anatomical literature, led to the appellation *Canales Brescheti* and was not subsequently reconsidered (e.g., Spalteholz, 1923). Anatomical textbooks in the English language (e.g., *Gray's Anatomy* [Warwick and Williams, 1973]) maintained Breschet's concept, apparently ignoring contrasting posits by French investigators (Testut, 1893). The latter recognized that Breschet's observations were not representative and that actual diploic venous patterns were quite variable. The French perspective was supported in the present study.

The five distinct tunnel distribution patterns identified and described in the present study are at variance with reports in dissection-based literature (e.g., *Traité d'Anatomie Humaine* (Testut, 1893), *Hand-Atlas of Human Anatomy* (Spalteholz, 1923), *Cunningham's Text-Book of Anatomy* (Brash and Jamieson, 1937), *An Atlas of Human Anatomy* (Anson, 1950), *Morris' Human Anatomy* (Anson, 1966), *Atlas of Human Anatomy* (Sobotta, 1963), *Gray's Anatomy* [Warwick and Williams, 1973]). Given the difficulty of dissecting diploic space structures, radiological examination of split skulls seems to provide clearer visualization and greater accuracy (Figs. 8, 9).

Anatomical textbooks describe a single diploic venous pattern (Fig. 1) and make no notation of possible variation. Significantly, the 108 cases in the present study manifest little resemblance to the textbook figures. Cunningham's (Brash and Jamieson, 1937) illustration (Fig. 1B) is somewhat similar to the hybrid type (which represents a distinct minority in this study), perhaps representing the chance specimen selected at the time of illustration. Gray's (Warwick and Williams, 1973) diploic vein illustration (Fig. 1A) may represent a hypothetical composite, as no comparable example is recognized in this study.

An attempt to correlate the diploic venous pattern types observed in the present study with the four major diploic veins mentioned in *Cunningham's Text-Book of Anatomy* (Brash and Jamieson, 1937) and *Gray's Anatomy* (Warwick and Williams, 1973) succeed only to a limited extent. The posterior temporal diploic vein in Gray's is comparable to our vine or bonsai pattern, while the anterior temporal is somewhat comparable to our coronal pattern. However, Gray's and Cunningham's textbooks appear to suggest that a standard distribution of individual veins is routinely present, while this study demonstrates variability. Three of the parietal diploic vein patterns observed (spider, serpentine, and thousand island) cannot be related in course, location, or associated cranial openings and sinuses to any of Gray's and Cunningham's classic diploic veins. While textbook descriptions may simply be reproductions of what originally were hypothetical representations, methodology could also account for the differences. Breschet's (1829) is an anatomic study, contrasted with the radiologic approach utilized in the current study. Given the difficulty of dissecting diploic space structures, radiologic examination of hemicrania may simply provide a clearer visualization and greater accuracy than was available more than 150 years ago.

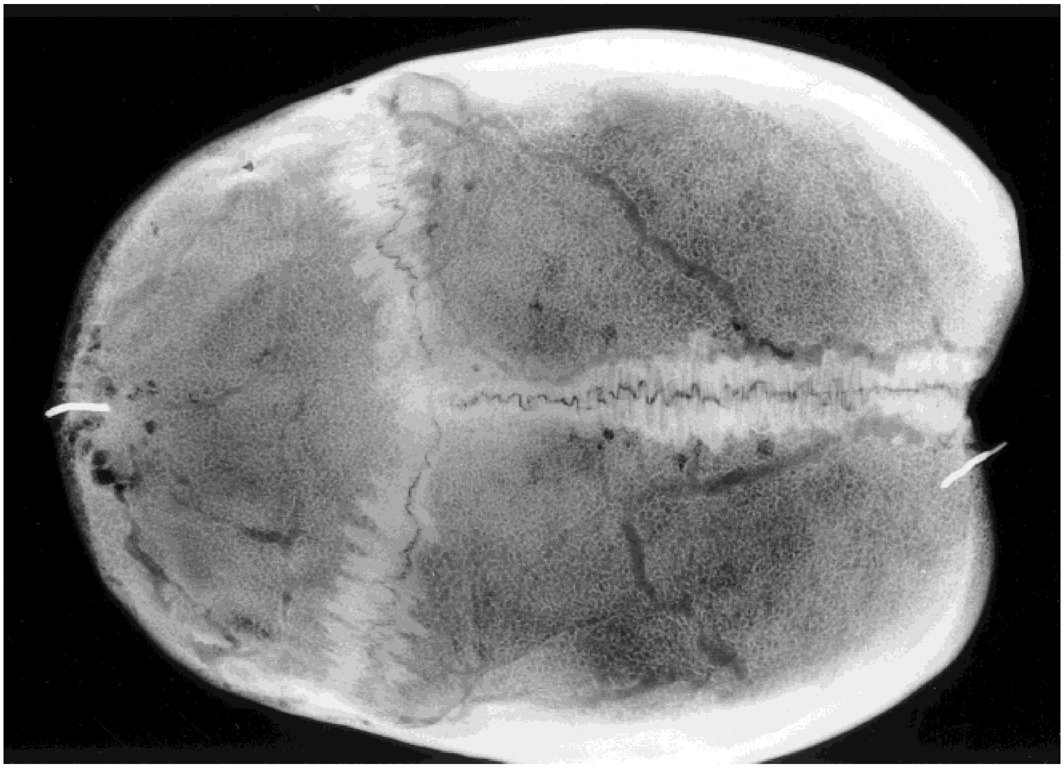

Fig. 5. Superior-inferior x-ray view of diploic vein pattern. Two large diploic veins running parallel to sagittal sinus. Notice the lack of full symmetry between the sides.

Neither Cunningham's (Brash and Jamieson, 1937:1250) nor Gray's (Warwick and Williams, 1973:691) statements that "The frontal diploic vein is one of the most constant" and that "The occipital diploic vein is usually the largest" were supported by the current study. In 23% of individuals examined, the frontal diploic vein was either missing or so small that it could hardly be seen on lateral radiographs. When observed, it varies greatly in size, location, and drainage apertures. Neither the midsagittal vein nor the occipital diploic vein, which is predominantly a continuation of the serpentine type, is the largest of the diploic veins.

The fragility of the fetal skull limits dissection possibilities, apparently responsible for several misconceptions regarding ontogeny of diploic veins (Testut, 1893; Warwick and Williams, 1973). These problems inherent in the dissection approach were overcome by use of x-ray technology. The statements appear in many anatomical textbooks (e.g., *Traité d'Anatomie Humaine* (Testut, 1893: 229) and *Gray's Anatomy* [Warwick and Williams, 1973]) that diploic veins "are absent from the skull of the newborn" or that they "begin to develop with the diploe at the age of about two years" could not be confirmed. Diploic veins are clearly present in 7–9-month-old fetuses (Fig. 6A). It is possible that Langer (1877), who found no diploic veins in newborns, is the source of the erroneous information on the fetal diploic venous system. Langer (1877) stated that these vessels arise on the interior of the skull from a vascular net which is gradually incorporated into the calvarial diploe and by the age of five is completely developed. Similarly, in a radiological study, Lindblom (1936) found that diploic channels undergo very little change after 5 years of age. In addition, the current study did not support the notion

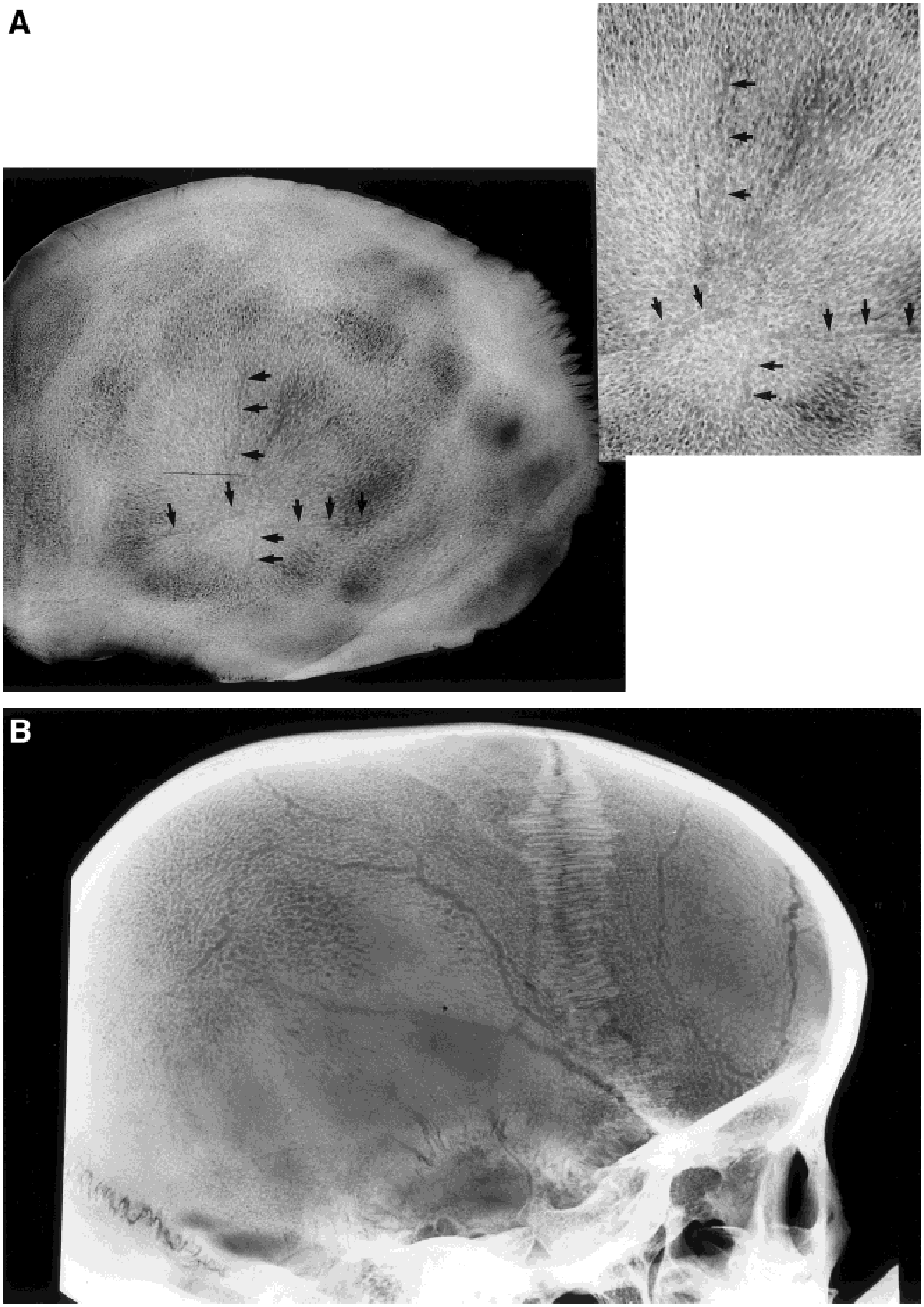

Fig. 6. Lateral x-ray view revealing presence of diploic veins. **A:** Seven-month-old fetus. Arrows indicate early diploic vein development. **B:** Four-year-old.

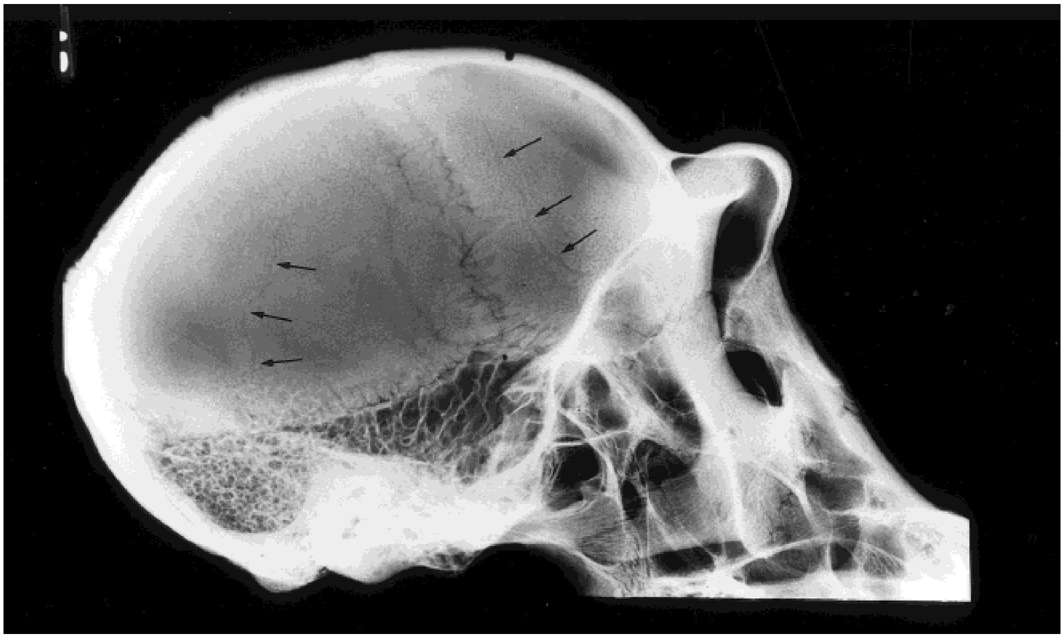

Fig. 7. Lateral x-ray view of a chimpanzee skull. Note the small, narrow diploic veins (arrows) in both parietal and frontal bone.

that diploic veins develop independently within individual skull bones (Testut, 1893).

Anthropological perspective of diploic veins

In general, the patterns and intensity of diploic veins are independent of sex, ethnic origin (Afro-American vs. Euro-American) and age (10 years cohorts). Skulls with well-developed diploic systems tend to be larger than skulls with only weakly developed diploic veins. Intensity grade IV is therefore rarely recognized in females, as it is a size factor and not a sex factor. Diploic vein characteristics do not appear to vary with age. The absence of an age factor stands in contrast to the notion that diploic veins develop continually, becoming larger and more complex with age (Testut, 1893). This raises the possibility that diploic venous patterns have a strong genetic base, amenable to population and familial study.

Evolutionary perspective of diploic veins

Since diploic veins provide an excellent anatomical means to explain the convection process of brain cooling, their study in early hominids may shed light on a recent and challenging theory in human evolution: the radiator theory (Falk, 1990). Although controversial (e.g., Braga and Boesch, 1977a,b; Falk and Gage, 1997), the radiator theory maintains that emissary veins function to cool the brain under conditions of hyperthermia (Cabanac, 1995). This network becomes increasingly extensive with brain expansion from gracile australopithecines to *Homo sapiens* (Falk, 1990). While our study did not deal directly with the evolutionary aspect of diploic veins, it was demonstrated that the diploic venous system in modern humans is more complex and developed than it is in their relatives, the apes.

Potential future applications

The establishment of criteria for analyzing diploic venous patterns may provide anthropologists with a new investigative tool of manifold value. The following are examples of future applications which may be of value.

1. While falling into general categories, diploic venous patterns resemble fingerprints in their individuality. A potential application in forensic medicine, skull glyph-

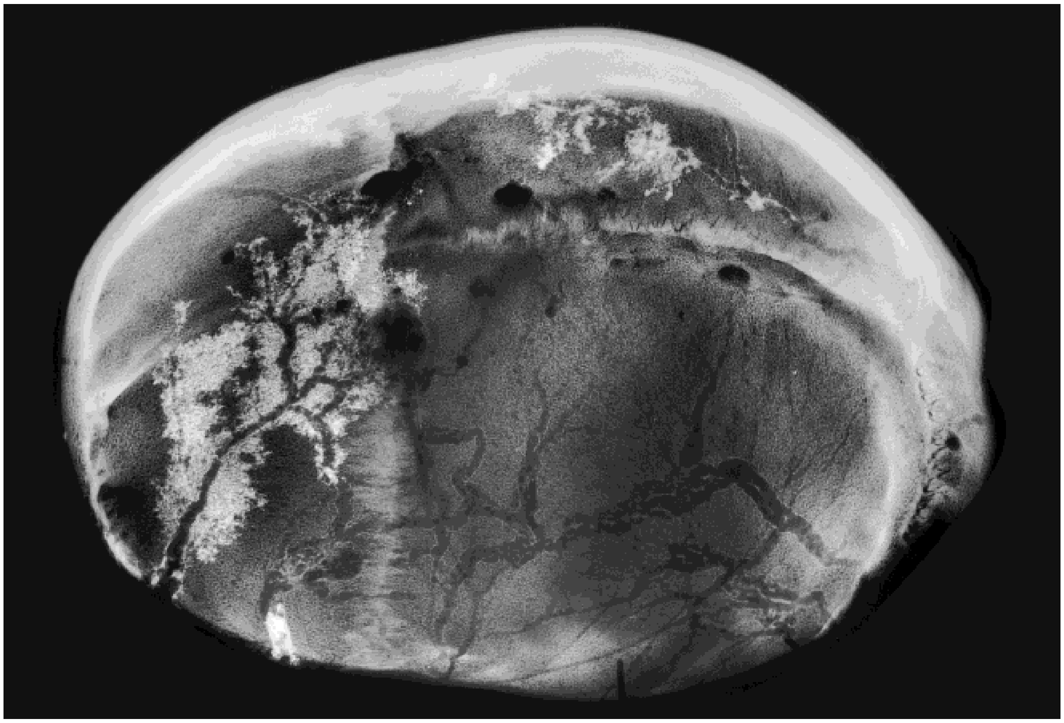

Fig. 8. Inferolateral view of injected (iodine) right frontal diploic vein. Some small branches are crossing the midline, anastomosing with the left frontal diploic vein.

ics, similar to dermatoglyphics, may be worthy of future investigation.

2. The possibility of establishing familial relationships based on skull glyphics should be addressed in future research.

3. Population studies may benefit from using this discrete trait which is less prone to environmental deterioration than some of those hitherto relied upon.

4. Diploic venous patterns in apes were more subtle and less complex than those in humans, and their intensity did not exceed grade I. Only one or two isolated, vertically oriented channels were noted in apes. To our knowledge, diploic patterns have yet to be studied in the fossil record.

5. Given the relationship of intensity to brain volume and complexity in humans, future studies on hominid evolution might benefit from the analysis of diploic venous patterns.

6. The distribution of emissary foramina (which are probably associated with the regulation of brain temperature) varies with the population geographical location. It is

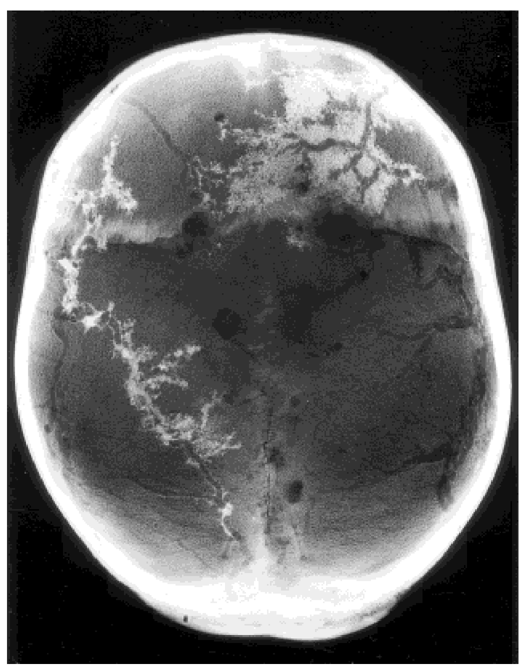

Fig. 9. Superior view of injected right frontal diploic vein and left parietal (marginal branch). Diploic veins are bilateral but not totally symmetrical.

therefore of interest to examine whether a relationship exists between diploic venous patterns and climate.

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LITERATURE CITED

Anson BJ, editor. 1966. Morris' Human Anatomy. New York: McGraw-Hill Book Company.

Anson BJ. 1950. An Atlas of Human Anatomy. Philadelphia: W.B. Saunders Company.

Baker MA. 1979. A brain cooling system in mammals. Sci Am 240:114–122.

Bass WM. 1987. Human Osteology. Columbia: Missouri Archaeological Society.

Braga J, Boesch C. 1997. Further data about venous channels in South African Plio-Pleistocene hominids. J Hum Evol 33:423–447.

Braga J, Boesch C. 1997. The “radiator” bias. A reply to Falk and Gage. J Hum Evol 33:503–506.

Brash JC, Jamieson EB. 1937. Cunningham’s Text-Book of Anatomy. New York: Oxford University Press.

Breschet MG. 1829. Recherches anatomiques, physiologiques et pathologiques sur le systeme veineux. Paris: Villeret.

Cabanac M. 1993. Selective brain cooling in humans: “fancy” or fact? FASEB J 7:1143–1146.

Cabanac M. 1995. Human Selective Brain Cooling. Heidelberg: Springer Verlag; Austin: Landes Publishing Co.

Corruccini RS. 1974. An examination of the meaning of cranial discrete traits for human skeletal biological studies. Am J Phys Anthropol 40:425–446.

Falk D. 1990. Brain evolution in *Homo:* the “radiator” theory. Behav Brain Sci 13:333–381 (with peer commentary).

Falk D, Gage TB. 1997. Flushing the radiator? A reply to Braga and Boesch. J Hum Evol 33:495–502.

Finnegan M, Cooprider K. 1978. Empirical comparison of distance equations using discrete traits. Am J Phys Anthropol 49:39–46.

Hecker CFF. 1845. Die anatomische Verhaltnisse und Krankheiten der Venae diploicae und Vasa emissaria. Erfahrungen und Abhandlungen im Gebiete der Chirurgie und Augenheilkunde. Erlangen: Verlag von Ferdinand Enke. p 136–158.

Langer K. 1877. Uber die Blutgefasse der Knochen des Schadeldaches und der harten Hirnhaut. Denkschr. d. kaiserl. Akad. d. Wissenschaften (Wien) 37:217–240.

Lindblom K. 1936. A roentgengraphic study of the vascular channels of the skull. Stockholm: Kungl. Boktryckeriet. P. A. Norstedt & Soner.

Rosenberg B, Hershkovitz I, Kobyliansky E, Arensburg B. 1983. Metric and non-metric variation in three isolated Bedouin populations of the Negev and South Sinai deserts. J Hum Evol 12:337–345.

Sobotta J. 1963. Atlas of human anatomy. New York: Hafner Publishing Company.

Spalteholz W. 1923. Hand-atlas of human anatomy. Philadelphia: J.B. Lippincott Company.

Testut L. 1893. Traité d’anatomie humaine. Paris: Octave Doin, Editeur.

Warwick R, Williams PL. 1973. Gray’s Anatomy. Philadelphia: W. S. Saunders Company.

Zenker W, Kubik S. 1996. Brain cooling in humans—anatomical considerations. Anat Embryol 193:1–13.